CAB INTERNATIONAL MYCOLOGICAL INSTITUTE LIBRARY
18 FEB 1992
GORDON, W. L.

EFFECT OF TEMPERATURE ON HOST REACTIONS TO PHYSIOLOGIC FORMS OF *PUCCINIA GRAMINIS AVENAE*, ERIKSS. & HENN.*

W. L. GORDON †
Dominion Rust Research Laboratory, Winnipeg, Man.
[Received for publication August 28, 1930]

INTRODUCTION

Since the study of physiologic forms of *Puccinia graminis avenae* Erikss. & Henn. was commenced at the Dominion Rust Research Laboratory, Winnipeg, in 1925, it has been noted at various times, particularly during the summer months, that the reaction of one differential host, Joanette Strain, to certain physiologic forms fluctuated beyond the normal limits. This was considered to be due partly to a genetic instability of this differential host and partly to the high temperature prevailing in the greenhouses during the summer. In 1929, temperature control apparatus was installed in two sections of one of the greenhouses. A study of the effect of temperature on the reactions of the differential hosts was thus made possible.

HISTORICAL

That temperature exerts a decided influence on the development of cereal rusts has been observed by numerous workers, including Christman (*2*), Freeman and Johnson (*3*), Fromme (*4*), Hecke (*5*), Hungerford (*6*) Lauritzen (*7*), Mains (*8*), Metha (*9*), Peltier (*10*), Stakman and Levine (*11*), and Ward (*12, 13*). Their observations or investigations dealt largely, however, with the effect of temperature on the amount of infection and the duration of the incubation period of the different cereal rusts. Waterhouse (*14*), in Australia, showed that changes in temperature affected the reactions of one differential host to certain physiologic forms of *Puccinia graminis avenae*. He found that Joanette Strain was resistant to Form 1 in the winter, susceptible to it in the summer, and gave a heterogeneous reaction in the spring and fall, but the reaction of this host to physiologic forms 2 and 7 throughout the year was not significantly changed.

EFFECT OF FOUR TEMPERATURES ON THE REACTIONS OF THE DIFFERENTIAL HOSTS TO EIGHT PHYSIOLOGIC FORMS

The effect of temperature on the reactions of the differential hosts to physiologic forms of *Puccinia graminis avenae* was studied in the following manner. A single spore culture of each of the eight physiologic forms was first obtained, and cultures derived from these single spores were used as inoculum throughout the study. The differential hosts, White Russian, Richland, Joanette Strain, and Victory were inoculated in the seedling stage, kept for 48 hours in moist chambers at the ordinary greenhouse temperature, and then placed in sections of the greenhouse which were maintanied at approximately constant temperatures. The reactions of the differential hosts to the eight physiologic forms were determined at four temperatures, 57.4° 64.8°, 71.9° and 75.4°F. These were the mean temperatures for the sections

*Contribution from the Division of Botany, Experimental Farms Branch, Department of Agriculture, Ottawa, Canada.
†Plant Pathologist.

Reprinted from Scientific Agriculture, Vol. XI., No. 2, October, 1930.

14 APR 1952

of the greenhouse during the complete development of the uredinial stage of the rust. Above or below each of these temperatures, the variation was not more than 2 degrees. During the winter months, the daylight was supplemented by artificial light at night.

The classes of host reaction and infection types used by Bailey (*1*) have been followed. They are as follows:

Classes of Host Reaction	Types of Rust Infection
Practically immune	0; No uredinia developed, but sharply defined hypersensitive flecks present.
Extremely resistant	1. Infection very light; uredinia minute, scattered, and surrounded by sharply defined necrotic areas.
Moderately resistant	2. Infection light; uredinia usually small and scattered, hypersensitive areas varying from sharply defined necrosis to pronounced chlorosis.
Moderately susceptible	3. Infection moderate; uredinia mid-sized with a tendency to coalesce; true hypersensitiveness absent, but more or less well marked chlorosis present.
Completely susceptible	4. Infection normal and heavy; uredinia large, numerous, and confluent; hypersensitiveness absent, but chlorosis may be present.
Indeterminate	X. Uredinia very variable, apparently including all types of infection, often on the same leaf-blade; no mechanical separation of the types seems possible, and the infection is ill-defined and heterogeneous.

Under these conditions, it was shown that temperature influences very definitely the reaction of a differential host to certain physiologic forms of *Puccinia graminis avenae*. There was no significant difference in the reactions of the differential hosts, White Russian, Richland, and Victory, to any of the physiologic forms at these temperatures. However, the reaction of Joanette Strain to forms 1, 3, 4, and 5, was decidedly changed. The reaction of this differential host to these four forms at the four temperatures is shown for one test in Table 1. Other tests with this differential host at the four temperatures already mentioned gave essentially the same results. The reaction of this differential host to forms 2, 6, 7, and 8, was not significantly affected by the higher temperatures.

The reactions given in Table 1 are to be interpreted as follows: The number below the line denotes the total number of plants inoculated; the number above the line and placed just before the bracketed number denotes the number of plants giving the type of reaction enclosed by the brackets; and the number which appears after a semicolon denotes the number of plants which are flecked. For example, the reaction of Joanette Strain at 75.4°F.

to physiologic form 1 in Table 1 denotes that, out of a total of thirteen plants inoculated, two plants gave a (4) type of reaction indicating complete susceptibility, while eleven plants gave a (3) type of reaction, indicating moderate susceptibility.

TABLE 1. *The reaction of Joanette Strain to Physiologic forms 1, 3, 4, and 5, at four different Temperatures.*

Form	Temperatures			
	75.4° F.	71.9° F.	64.8° F.	57.4° F.
1	$\frac{2(4)c11(3)cn^{-\ \pm}}{13}$	$\frac{1(4)2(X)5(1)\pm}{10}$	$\frac{1(4)11(X)3(1)}{15}$	$\frac{11(1)-;2}{14}$
3	$\frac{13(4)cnl(3)cn^{=\ -}}{14}$	$\frac{5(3)cn6(X)cn^{\pm}}{12}$	$\frac{6(X)-10(1)\pm}{16}$	$\frac{1(1)-;6}{7}$
4	$\frac{10(4)c^{+}}{10}$	$\frac{12(4)cn^{\pm}}{12}$	$\frac{7(3)\pm4(X)1(1)}{14}$	$\frac{2(1)-;11}{14}$
5	$\frac{12(4)+}{12}$	$\frac{17(4)\pm}{17}$	$\frac{16(4)}{16}$	$\frac{11(X)-2(4)-}{16}$

Explanation of Symbols: Plus and minus signs indicate a slightly greater or less amount of rust than the nearest figure representing the infection type. The semicolon indicates the presence of flecks. The sign "cn" indicates that hyper-sensitiveness ranging from chlorosis to necrosis typically accompanies the infection. These symbols are also used in Tables 3-10.

According to the analytic key for the identification of physiologic forms of *P. graminis avenae* prepared by Bailey (*1*), Joanette Strain is resistant to forms 1, 3, and 4, and gives a heterogeneous (X) reaction to form 5. It will be seen from Table 1 that, at 57.4°F., this host reacts normally to these forms; but, at the higher temperatures, its reactions are heterogeneous and abnormal. Thus it would appear that only at a comparatively low temperature do these forms produce on Joanette Strain the characteristic reactions which have hitherto served, in part, for their identification as forms 1, 3, 4, and 5. These forms, at the higher temperatures, do not produce these reactions, but instead, reactions which may be identical with those of other forms. In Table 2 are given the forms under which forms 1, 3, 4, and 5 would be classified at the four temperatures.

TABLE 2. *Changes in the identification of physiologic forms 1, 3, 4 and 5, due to the effect of temperature on the reaction of the differential host, Joanette Strain.*

Form	Temperatures			
	75.4° F.	71.9° F.	64.8° F.	57.4° F.
1	2	5	5	1
3	7	new form	new form	3
			same	
4	6	6	new form	4
5	2	2	2	5

The reaction shown by the differential host, Joanette Strain, to physiologic form 4 at the temperatures 57.4° and 75.4°F., is shown by means of a photograph in Fig. 1. This host was extremely resistant when kept at 57.4° and was completely susceptible at 75.4°F.

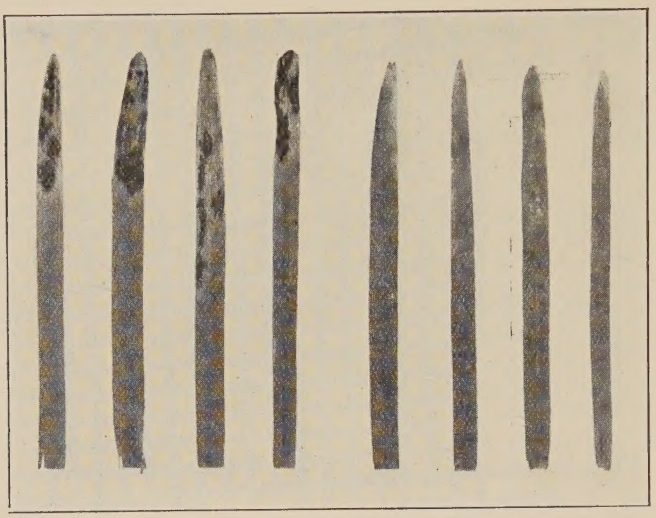

Figure 1. The reaction of Joanette Strain to Form 4 at temperatures of 57.4°F. (right), and at 75.4°F. (left).

Effect of a Change in Temperature on the Reaction of Joanette Strain to Four Physiologic Forms

A further study was made to determine the effect on the reaction of Joanette Strain to forms 1, 3, 4, and 5, when the temperature at which it was kept during the development of the rust was changed. Seedlings of Joanette Strain growing in pots were inoculated and then placed in moist chambers for 48 hours at the ordinary greenhouse temperature. Eighteen pots were inoculated with each of these forms. Nine pots were placed in a section of the greenhouse maintained at a low temperature (60.8°F.), and nine in a section maintained at a high temperature (76.8°F.). After one day, and on each succeeding day for seven days, one pot was transferred from the low to the high temperature, and one from the high to the low temperature. One pot was kept as a control in each section. The results of this experiment are given in Table 3-10.

It is evident from Tables 3-10 that Joanette Strain gave a very heterogeneous reaction to forms 1, 3, 4, and 5, when the temperature at which it was kept during the development of the rust was changed. The longer the period Joanette Strain was kept at a temperature of 60.8°F. during the development of the rust before it was transferred to a temperature of 76.8°F., the greater was the resistance it showed (Tables 3, 5, 7, 9). Conversely, the longer the period this host was kept at a temperature of 76.8°F., during the development of the rust before it was transferred to a temperature of 60.8°F., the greater was its susceptibility (Tables 4, 6, 8, 10). When kept at a temperature of 60.8°F., during the complete development of the

TABLE 3. *The reaction of Joanette Strain to form 1 when kept for different lengths of time at a temperature of 60.8° F., and then transferred to a temperature of 76.8° F.*

Kept 1 day at 60.8° F	$\frac{6(4)\overline{cn}6(X)1(1)+}{13}$
" 2 days "	$\frac{5(X)9(1)}{14}$
" 3 " "	$\frac{2(X)6(1)}{9}$
" 4 " "	$\frac{10(X)1(1)}{13}$
" 5 " "	$\frac{3(X)5(1),1}{10}$
" 6 " "	$\frac{2(X)-6(1):2}{11}$
" 7 " "	$\frac{3(X)-6(1)=;4}{14}$
Kept continuously at 60.8° F	$\frac{1(X)=6(1)-;1}{9}$
Kept continuously at 76.8° F	$\frac{3(4)\overline{cn}2(1)+}{7}$

TABLE 4. *The reaction of Jaonette Strain to form 1 when kept for different lengths of time at a temperature of 76.8° F. and then transferred to a temperature of 60.8° F.*

Kept 1 day at 76.8° F	$\frac{3(X)=4(1)-;2}{9}$
" 2 days "	$\frac{2(X)=5(1)-}{7}$
" 3 " "	$\frac{3(1)-5(1)\pm}{8}$
" 4 " "	$\frac{\pm 6(3)\overline{cn}3(X)--}{10}$
" 5 " "	$\frac{\pm 5(3)\overline{cn}2(X)}{7}$
" 6 " "	$\frac{\pm 7(3)\overline{cn}2(X)}{9}$
" 7 " "	$\frac{\pm 8(3)\overline{cn}8(X)}{16}$
Kept continuously at 76.8° F	$\frac{-\ \pm 1(4)c3(3)\overline{cn}2(X)1(1)}{8}$
Kept continuously at 60.8° F	$\frac{1(X)=4(1)-;2}{8}$

TABLE 5. *The reaction of Joanette Strain to form 3 when kept for different lengths of time at a temperature of 60.8° F. and then transferred to a temperature of 76.8° F.*

Kept 1 day at 60.8° F	$\frac{4(c)cn3(X)-6(1)}{15}$
" 2 " "	$\frac{1(3)cn6(1)-;6}{14}$
" 3 " "	$\frac{1(1)-;7}{10}$
" 4 " "	$\frac{1(1)-;10}{11}$
" 5 " "	$\frac{1(1)-;10}{14}$
" 6 " "	$\frac{0;11}{15}$
" 7 " "	$\frac{0;7}{14}$
Kept continuously at 60.8° F	$\frac{0;3}{8}$
Kept continuously at 76.8° F	$\frac{6(4)cn4(X)}{11}$

TABLE 6. *The reaction of Joanette Strain to form 3 when kept for different lengths of time at a temperature of 76.8° F. and then transferred to a temperature of 60.8° F.*

Kept 1 day at 76.8° F	$\frac{3(1)=;9}{12}$
" 2 " "	$\frac{1(X)-14(1)-;1}{16}$
" 3 " "	$\frac{8(X)-4(1)\pm}{12}$
" 4 " "	$\frac{1(3)cn9(X)}{12}$
" 5 " "	$\frac{1(3)cn6(X)1(1)}{8}$
" 6 " "	$\frac{4(3)cn5(X)}{10}$
" 7 " "	$\frac{4(3)cn4(X)}{8}$
Kept continuously at 76.8° F	$\frac{1(4)7(3)+cnl(X)}{10}$
Kept continuously at 60.8° F	$\frac{0;7}{10}$

TABLE 7. *The reaction of Joanette Strain to form 4 when kept for different lengths of time at a temperature of 60.8° F. and then transferred to a temperature of 76.8° F.*

Kept 1 day at 60.8° F	1(4)c4(3)+−6(X)
	12
" 2 " "	3(3)+−6(X)+
	10
" 3 " "	5(X)6(1)+−
	11
" 4 " "	1(3)+6(X)−4(1)
	12
" 5 " "	1(X)−4(1)−;6
	12
" 6 " "	1(X)−6(1)−;5
	13
" 7 " "	1(X)=3(1)−;7
	7
Kept continuously at 60.8° F	5(1)=;5
	10
Kept continuously at 76.8° F	13(4)+−5(X)+
	18

TABLE 8. *The reaction of Joanette Strain to Form 4 when kept for different lengths of time a a temperature of 76.8° F., and then transferred to a temperature of 60.8° F.*

Kept 1 day at 76.8° F	7(1)−;1
	9
" 2 " "	4(1)−1(X)=;2
	9
" 3 " "	7(1)4(X)=;1
	13
" 4 " "	2(1)6(X)1(3)c+
	10
" 5 " "	1(4)2(X)3(1);2
	10
" 6 " "	3(4)5(X)+
	8
" 7 " "	5(4)3(3)c1(X)+
	10
Kept continuously at 76.8° F	9(4)±1(X)+
	10
Kept continuously at 60.8° F	4(1)−;3
	8

TABLE 9. *The reaction of Joanette Strain to form 5 when kept for different lengths of time at a temperature of 60.8° F., and then transferred to a temperature of 76.8° F.*

Kept 1 day at 60.8° F	14(4)	+ −
	14	
" 2 " "	11(4)c	
	11	
" 3 " "	9(4)c 1(X)	+
	11	
" 4 " "	5(4)c 2(3)cn	−
	7	
" 5 " "	10(4)c 2(X)	−
	13	
" 6 " "	1(4)c 8(X)	−
	9	
" 7 " "	6(X) 1(1)	
	9	
Kept continuously at 60.8° F	7(X) 2(4)cn	=
	9	
Kept continuously at 76.8° F	12(4)c	+
	12	

TABLE 10. *The reaction of Joanette Strain to form 5 when kept for different lengths of time at a temperature of 76.8° F., and then transferred to a temperature of 60.8° F.*

Kept 1 day at 76.8° F	9(X)3(3)cn	±
	13	
" 2 " "	9(X)3(3)cn	±
	12	
" 3 " "	3(X)10(4)cn	−
	14	
" 4 " "	2(X)9(4)cn	−
	11	
" 5 " "	1(X)	+ 12(4)c
	13	
" 6 " "	13(4)c	±
	12	
" 7 " "	12(4)	±
	12	
Kept continuously at 76.8° F	10(4)	+
	10	
Kept continuously at 60.8° F	10(X) 2(4)c	=
	12	

rust, Joanette Strain was resistant to forms 1, 3, and 4; but kept at 76.8°F., for the same period it was susceptibile or heterogeneous in its reaction. It gave the normal heterogeneous reaction to form 5 when kept at a temperature of 60.8°F., but it was susceptible to form 5 at 76.8°F.

Conclusions

These results at least partly explain why the reaction of Joanette Strain to physiologic forms, 1, 3, 4, and 5, fluctuated at certain times in the past. The variations in temperature which occur under ordinary greenhouse conditions had undoubtedly affected the reaction of this host. Certain recent observations suggest that light is also a factor in influencing the reaction of Joanette Strain to these forms, but the relation of different intensities of light to host reactions has yet to be definitely determined.

Summary

No significant deviations from the normal reactions of the differential hosts, White Russian, Richland, and Victory, to physiologic forms of *Puccinia graminis avenae* occurred at temperatures of 57.4°, 64.8°, 71.9°, and 75.4°F.

The effect of temperature on the reactions of all the differential hosts to physiologic forms 2, 6, 7, and 8, under the conditions of this study, was negligible.

Joanette Strain showed a striking difference in its reactions to forms 1, 3, 4, and 5, at a low (57.4°F.) and at a high (75.4°F.) temperature.

Temperature fluctuations seem to account satisfactorily for variations previously observed in the reaction of Joanette Strain to forms 1, 3, 4, and 5.

LITERATURE CITED

1. Bailey, D. L. Physiologic Specialization in *Puccinia graminis avenae* Erikss. and Henn. Minn. Agr. Exp. Sta. Tech. Bull. 35, 1925.
2. Christman, A. H. Observations on the Wintering of Grain Rusts. Trans. Wisconsin Acad. Sci. Arts, and Letters. *15*: 98, 1907.
3. Freeman, E. M. and E. C. Johnson. The rusts of grains in the United States. U.S.D.A., B.P.I. Bull. 216. 1911.
4. Fromme, F. D. The culture of cereal rusts in the greenhouse. Bull. Torrey Bot. Club *40*: 501-521, 1913.
5. Hecke, L. Beobachtungen der Uberwinterungsart von Pflanzenparasiten. Naturw. Ztschr. Landw. u. Forstw. *9*: 44-53, 1911.
6. Hungerford, C. W. Studies on the life history of stripe rust, *Puccinia glumarum* (Schm.) Erikss. and Henn. Jour. Agr. Res. *24*: 607-620, 1923.
7. Lauritzen, J. I. Relations of temperature and humidity to infection by certain fungi. Phytopath. *9*: 7-35, 1919.
8. Mains, E. B. The relation of some rusts to the Physiology of their Hosts. Amer. Jour. Bot. *4*: 179-219, 1917.
9. Metha, K. C. Observations and experiments on cereal rusts in the neighborhood of Cambridge, with special reference to their annual recurrence. Trans. British Mycol. Soc. *8*: 142-176, 1923.
10. Peltier, G. L. A study of the environmental conditions influencing the development of stem rust in the absence of an alternate host. II. Infection studies with *Puccinia graminis tritici* Form III. and Form IX. Nebraska Agr. Exp. Sta. Res. Bull. 25. 1923.
11. Stakman, E. C. and M. N. Levine. Effect of certain ecological factors on the morphology of the Urediniospores of *Puccinia graminis*. Jour Agri. Res. *16*: 43-77, 1919.
12. Ward, H. M. On the relations between host and parasite in the bromes and their brown rust. Annals of Botany *16*: 233-315, 1902.
13. ————. Recent researches on the parasitism of fungi. Annals of Botany *19*: 1-50, 1905.
14. Waterhouse, W. L. Australian rust studies I. Proc. Linnean Soc. N.S.W. *54*: 615-680. 1929.